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XXII.

ON THE GROUP "*b*" IN THE SOLAR SPECTRUM.

BY WILLIAM C. WINLOCK.

Presented by Prof. Wolcott Gibbs, June 9, 1880.

THE most complete charts of the solar spectrum now available are Kirchhoff's, which were published in 1861, and Ångström's, published in 1869. Kirchhoff employed a battery of four flint-glass prisms, with a collimator and observing telescope each of about 4 centim. aperture and 49. centim. focal length; while Ångström used telescopes of about 4.6 centim. aperture, and 36.3 centim. focal length, and a diffraction grating made by Nobert, containing about 133 lines to the millimetre.

Such great advances have been made very recently in the construction of optical instruments, and more especially in the ruling of diffraction gratings, that it would now be possible to enlarge Ångström's great chart almost as much as he improved upon Fraunhofer's first maps. But it would be an almost endless undertaking for a single observer to attempt a map of the whole spectrum, from the ultra-violet to the invisible red, brought to light by our most powerful instruments, and accordingly most physicists who have paid especial attention to solar spectroscopy have devoted themselves to a careful study of detached portions which appear of unusual interest. As a slight contribution to this work, the following observations upon the group of dark lines "*b*," of the solar spectrum, were undertaken at the suggestion of Dr. Gibbs, and carried on under his immediate supervision.

A table of wave-lengths, based upon the wave-lengths of Ångström's lines, has been computed, and, in addition to this, the wave-lengths of all new lines within the limits adopted, have been deduced by graphical interpolation, in order to give a check upon the values obtained for λ in the table on page 403.

The group "*b*" is readily distinguished about the middle of the green by its two bold components visible with very low dispersive power, or by its three heavy and burred lines when seen under higher power. Its position near the brightest part of the spectrum, together with the readiness with which it can be recognized, make this group one of more than common interest. Moreover, since it combines, within very narrow limits, lines of almost every grade of heaviness and character, it would seem to have every qualification for a "test group" upon which the performance of any spectroscope may be tried. Indeed, for such a purpose it is equalled by few, and surpassed by no other groups of the spectrum.

The following is a brief description of the instruments employed: —

The spectroscope is mounted on a four-legged table, and the light is received through a circular aperture 11 centim. in diameter, from a "porte-lumière" fixed in a window upon the southern face of the building. The mirror of the *porte-lumière* is of silvered glass, and measures 10 centim. by 26 centim., and in this position can reflect the sunlight for about four hours only, during the day; that is, from 9 A.M. to 1 P.M. Before falling upon the slit of the collimating telescope, the light passes through a small cylindrical *condensing lens* measuring 4 centim. each way, with a focal length of 25.6 centim. This condenser is held in front of the slit by means of a wooden clamp. The *collimator* has an aperture of 4.76 centim., and focal length of 50 centim. The slit is 2.1 centim. long, and its width is adjustable by a rather coarse-threaded screw. The *observing telescope* is of 4.7 centim. aperture, and 49.6 centim. focal length. Three eyepieces can be used, and have been designated 1, 2, and 3. Their magnifying powers are approximately 35, 25, and 18 diameters. Both observing telescope and collimator admit of motion about two centres, so that proper adjustment can be made for any part of a grating, or for any number of prisms.

It was found that, owing to unsteadiness in the instrument, no accurate measurements could be made with the filar micrometer; so, abandoning the micrometer, a finely divided scale, with which all the measures were made, was placed in the highest power eyepiece. This method of measurement appears to possess all the accuracy attainable under the circumstances. The "eyepiece scale" was ruled by Professor W. A. Rogers upon a piece of glass 0.5 mm. in thickness, and 19 mm. diameter, cemented to a diaphragm at the focus of the eyepiece. The lines of the scale are seen with great distinctness, and, owing to the thinness of the glass upon which they are ruled, no appreciable amount of light is lost. Through the kindness of Professor Rogers I have been enabled to make a careful investigation of the errors of this scale, and a determination of the values of its divisions. The results show that the maximum error in one division is 0.003 scale div., a quantity entirely insensible in the present investigation, since at best it is possible to estimate to hundredths of a division. The actual value of one division is $\frac{1}{480}$th of an inch = 0.053 of a millimetre.

During the progress of the work two ends were held in view: First, to obtain data for comparing the appearance of the group under different conditions of the atmosphere, of dispersive power, etc.; and secondly, to measure the positions, and thus determine the wave-lengths of all lines seen with certainty within the assumed limits. For the first purpose mentioned, an enlarged copy of Ångström's chart was prepared, and below this were roughly sketched, on the various days of observation, the lines which were seen, — the grating and power being noted in the margin. All lines which could be measured were afterwards accurately entered upon the chart, and those which were not seen a second or third time were entered by estimation. In this way I obtained twenty-three observations of the group, between November, 1879, and May, 1880, using eight diffraction gratings and two prisms. Four of the gratings were ruled by Rutherfurd, of 17,296, 8,640, 13,321, and 7,021 lines per inch respectively; three by Professor Rogers, of 2,540, 2,540, and 5,080 lines per inch; one by Brunner, of 2,540 lines per inch. Grating 17,296 is on speculum metal, the ruled surface measuring 4.3 centim. in length by 4.8 centim. in width. Observations were usually made upon the spectrum of the second order. Dispersive power = 1860. Grating 13,321, silvered glass. Grating 7,021, on speculum metal covered with glass. The three gratings of 2,540 lines were ruled upon glass prepared by Brunner Frères, and were used for transmitted spectra. Grating 5,080 was ruled upon ordinary "commercial crystal" glass, and seems far superior to several gratings ruled upon better quality of glass, and showing less error in the spacing and cut of the lines. This grating was also used for transmitted spectra. A comparison of the three 2,540 gratings seems to show that those ruled by Professor Rogers are fully equal, if not superior, to Brunner's.

In the preparation of the chart given in Plate II., Rutherfurd's grating of 8,640 lines was used. This is ruled upon speculum metal with the following memorandum upon its edge: — "Aug. 2, 1877, 8,640 per in., 17,640 spaces. Man'f by D. C. Chapman with Mr. Rutherfurd's Engine. 175, 2 Ave., N. Y." The length of the lines is 4.3 centim., and the width of the ruled surface 5.2 centim. As far as working power is concerned, this grating seemed better than the one of 17,296 lines per inch, — at least under ordinary conditions of the atmosphere. For the dispersive power* we shall have, according to the formula given by Professor Pickering (vol. xi. (N. S. iii.), p. 273, Proc. Am. Acad.),

$$\frac{dr}{d\lambda} = \frac{(340)\ (3)}{.719} = 1419,$$

the observations being made upon the third order of spectrum with an angle of reflection of 44°.

To determine the wave-lengths of the thirty-seven lines given in Plate II., it was only necessary to note the position of each line upon the "eyepiece scale," and, having found the value of a division of the scale in wave-lengths, to reduce the scale readings to wave-lengths and add them to the wave-length of the line upon which the zero of the scale was set. In this way the absolute wave-lengths were made to depend, practically, upon the wave-length of the initial line, as assumed from Ångströms chart.

It was a matter of no small difficulty to decide upon the positions of some lines, owing to their excessive faintness, and discrepancies in the readings are not to be wondered at. A few preliminary measurements were found to be somewhat discordant, but this was probably due to parallax in the scale, which was discovered a little out of focus. I concluded, therefore, that the most accurate results would be obtained by employing a set of measurements all made on the same day, since relative positions only were required. On May 15, 1880, five independent sets of readings were made, each set including the whole number of lines to be measured.

The first line of the scale was set upon the line designated b^1, by the aid of a slow motion screw, and the readings of the different lines up to b^{37} noted by estimation to hundredths of a division. A single reading cannot be relied upon within, perhaps, one-tenth of a division, but in some cases it seemed advantageous to attempt a closer estimation. Ten readings of the lines b^6, b^{14}, b^{33}, and b^{37} were made. The probable error of a single reading of b^{37} is ± .014 div., and the probable error of the mean of ten readings ± .005 div. Where but five readings were made, as, for instance, b^{13}, the probable error of a single observation is ± .028, and the probable error of the result ± .013 scale divisions, corresponding to 0.011 tenth metres.

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* Ångström used dispersive powers of 665 and 798.

If, then, we put

$\lambda_0 =$ the wave-length of the initial line b^1

and $\lambda_x =$ the wave-length of a line whose reading upon the scale is x,

we shall have

$$\lambda_x - \lambda_0 = x\,\rho$$

where ρ is a constant factor (the equivalent in wave-lengths of one division of the scale), which must be obtained from the lines of known wave-length (i. e., λ_x given), by the relation

$$\rho = \frac{\lambda_x - \lambda_0}{x}$$

or, putting for convenience

$$\lambda_x - \lambda_0 = \Delta\,\lambda$$

we have

$$\rho = \frac{\Delta\,\lambda}{x}$$

and

$$\Delta\,\lambda = x\,\rho.$$

For the determination of ρ I have used the wave-lengths of all lines given by Ångström, except b^3 and b^5, and for these Ångström gives but a single value, 5164.59, which appears to be about their mean wave-length. The mean of fifteen values of ρ thus obtained is

$$\rho = 0.85476 \qquad \log \rho = 9.93184$$

How nearly this value satisfies each of the lines by means of which it was obtained, may be seen by comparing the last two columns in the table upon page 403.

Having found ρ, the wave-length, λ_x, of any unknown line is readily determined, for we see

$$\lambda_x = \lambda_0 + x\,\rho,$$

or

$$\lambda_x = \lambda_0 + \Delta\,\lambda.$$

This last quantity, $\lambda_0 + \Delta\,\lambda$, is found on page 403, and the corresponding "λ" of Ångström's lines are given in the next column. All wave-lengths are expressed in "tenth-metres," a tenth-metre being $\frac{1}{10^{10}}$ of a metre: for instance, the wave-length of b^1 is

0.000000516162 metre.

Taking for abscissas the readings, x, of the scale, and for ordinates the wave-lengths of the corresponding lines as given by Ångström, a "curve of wave-lengths" was drawn through the points found. The wave-lengths thus graphically deduced were found to agree closely with those computed in the table below. The "intensity" or heaviness of the lines has been estimated roughly by the eye, taking the intensity of b^1 as unity. The mean of three separate estimations is given upon the next page, and these intensities have been used in forming the chart, Plate II. For convenience the wave-lengths λ, and intensities I. are placed together in a table upon page 404.

TABLE OF WAVE-LENGTHS: — GROUP "*b*."

Line.	I.	II.	III.	IV.	V.	Mean (x)	Δ λ	$\lambda x = \lambda_0 + \Delta\lambda$	λ Ångström.
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5161.62	5161.62
2	0.80	0.80	0.70	0.90	0.70	0.78	0.67	62.29	
3	2.78	2.70	2.75	2.75	2.80	2.76	2.36	63.98	
4	3.10	3.10	3.08	3.10	3.10	3.10	2.65	64.27	
5	3.80	3.65	3.80	3.75	3.80	3.76	3.21	64.83	
6	4.75	4.70	4.80	4.75	4.80	4.76	4.07	65.69	65.74
7	5.00	5.00	5.00	5.00	5.00	5.00	4.27	65.89	
b_4 8	6.01	6.09	6.03	6.03	6.03	6.04	5.16	66.78	66.75
9	7.60	7.45	7.45	7.40	7.40	7.46	6.38	68.00	
$_3$10	7.97	7.90	7.90	7.90	7.90	7.91	6.76	68.38	68.34
11	8.10	8.05	8.10	8.10	8.10	8.09	6.91	68.53	
12	9.90	9.90	9.90	9.94	9.90	9.91	8.47	70.09	
13	10.00	10.03	10.08	10.08	10.10	10.06	8.60	70.22	
14	10.98	11.00	10.98	10.97	11.00	10.99	9.39	71.01	71.06
$b_2$15	12.00	12.10	12.10	12.10	12.10	12 08	10.32	71.94	72.02
16	13.10	13.19	13.20	13.20	13.20	13.18	11.26	72.88	
17	16.10	16.00	16.00	16.10	16.00	16.04	13.71	75.33	
18	16.90	16.95	16.75	16.80	16.77	16.83	14.39	76.01	75 59
19	17.40	17.40	17.40	17.40	17.40	17.40	14.87	76.49	76.38
20	17.70	17.75	17.65	17.75	17.70	17.71	15.14	76.76	
21	19.20	19.10	19.10	19.10	19.10	19.12	16.34	77.96	78.13
22	19.65	19.78	19.75	19.80	19.65	19.73	16.86	78.48	
23	20.95	20.90	20.90	20.85	20.90	20.90	17.86	79.48	79.52
24	22.10	22.18	22.10	22.10	22.10	22 12	18.91	80.53	
25	22.90	22.90	23.00	22.95	22.90	22.93	19.60	81.22	
$b_1$26	25.00	24.98	24.98	24.98	24.98	24.98	21.35	82.97	82.96
27	25.83	25.70	25.80	25.70	25.65	25.77	22.03	83.65	
28	25.98	26.00	25.98	25.98	25.99	25.99	22.21	83.83	
29	27.30	27.50	27.50	27.45	27.40	27.43	23.45	85.07	85.10
30	28.10	28.20	28.20	28.10	28.20	28.16	24.07	85.69	
31	29.80	29.90	29.97	29.90	29.95	29.90	25.56	87.18	87.35
32	30.10	30.10	30.10	30.10	30.10	30.10	25.73	87.35	
33	31.00	30.97	31.00	31.00	31.00	30.99	26.49	88.11	88.18
34	31.90	32.00	31.80	31.90	31.80	31.88	27.25	88.87	
35	34.03	34.05	34.10	34.00	34.00	34.04	29.10	90.72	90.53
36	34.97	34.90	34.70	34.70	34.80	34.81	29.75	91.37	
37	35.10	35.10	35.10	35.10	35.08	35.10	30.00	5191.62	5191.65

TABLE OF WAVE-LENGTHS AND INTENSITIES:—GROUP “*b*.”

Line.	I.	λ	Line.	I.	λ
1	1.0	5161.62	20	0.2	5176.76
2	0.1	62.29	21	0.4	77.96
3	0.6	63.98	22	0.2	78.48
4	0.4	64.27	23	0.7	79.48
5	0.8	64.83	24	0.3	80.53
6	0.9	65.69	25	0.1	81.22
7	0.1	65.89	26	2.7	82.97
8	2.9	66.78	27	0.3	83.65
9	0.2	68.00	28	0.3	83.83
10	1.6	68.38	29	0.7	85.07
11	0.1	68.53	30	0.3	85.69
12	0.2	70.09	31	0.6	87.18
13	0.2	70.22	32	0.1	87.35
14	1.0	71.01	33	1.7	88.11
15	2.7	71.94	34	0.1	88.87
16	0.9	72.88	35	1.6	90.72
17	0.1	75.33	36	0.1	91.37
18	0.7	76.01	37	1.6	5191.62
19	0.2	5176.49			

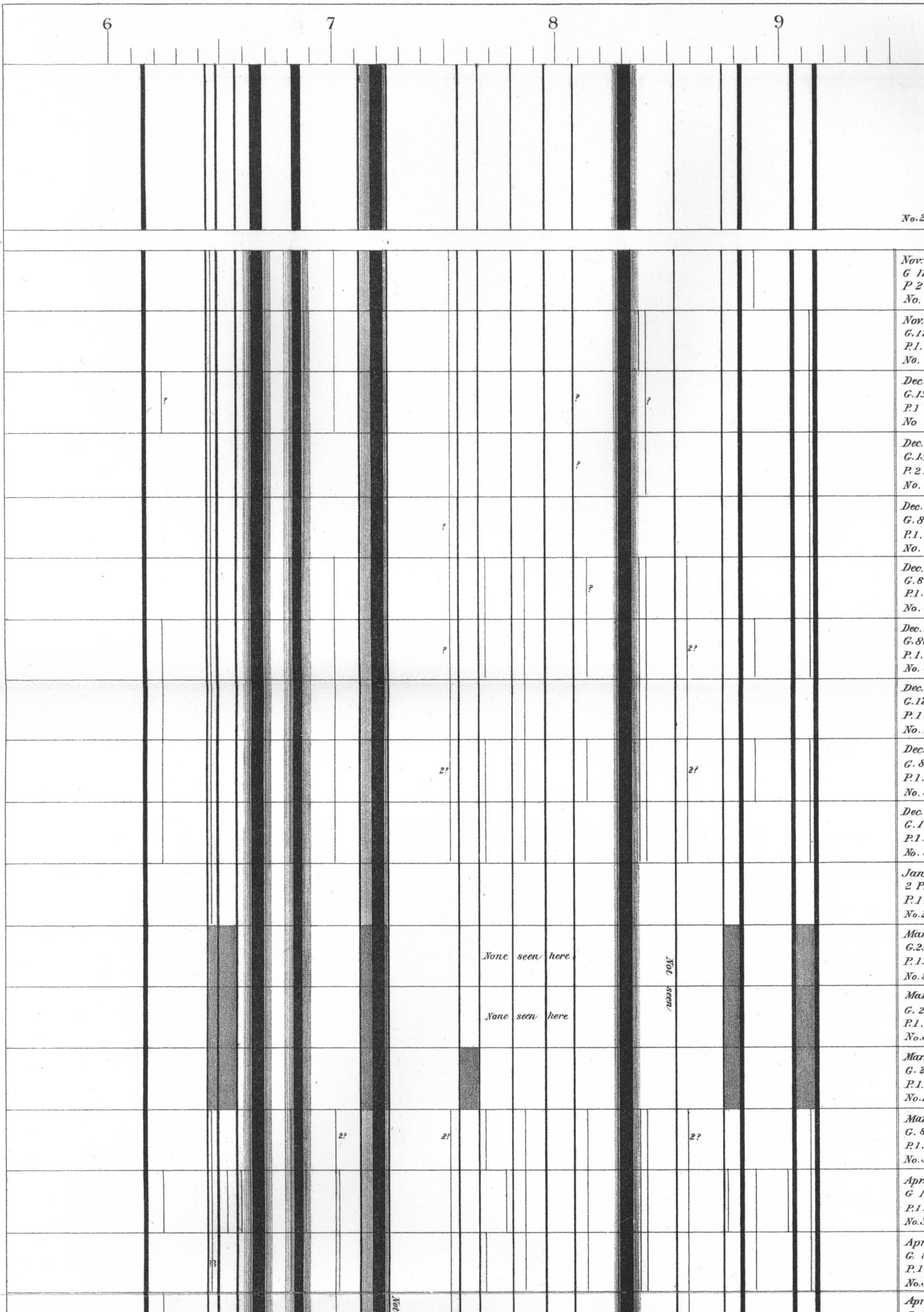
Plate I. At the head appears Ångström's chart of the group, enlarged four times. A map quite similar to this plate was prepared and upon it was sketched, each day, the appearance of the group as seen with the particular grating employed. The position of any new line was estimated from its relation to those adjoining, and the eyepiece scale was not used. The date, grating, power of eyepiece, number of lines seen, and order of spectrum, whenever noted, are given in the margin. The two sketches given on Dec. 17, 1879, were made with the help of a large collimating telescope of 6.7 centim. aperture, and 1.62 centim. focal length, but it appeared to possess little, if any, advantage over the shorter collimator. On Jan. 2, 1880, the chart was made from one flint glass and one bisulphide of carbon prism, each prism having a refracting angle of 60°: Where two lines were not separated by the 2540 gratings, I have indicated the fact by blending them upon the chart; and where there was any question as to the visibility of a line, an interrogation mark has been placed opposite.

Plate II. gives the final determination of the “*b*” Group upon a scale four times that of Ångström, and also shows the group as given in the charts of Kirchhoff and Ångström, the scale being unaltered in either case. Ångström gives 20, Kirchhoff 17 lines. The chart contains all the lines given by Ångstrom, together with such additional lines as it was possible to measure. The limits of the group were assumed arbitrarily, and the lines numbered from 1 to 37 inclusive. To avoid confusing lines thus designated with those called by Ångström b_1, b_2, b_3, b_4, it will be necessary to write these figures above the line, as b^5, b^{32}, etc. It might be noticed here that each of the lines b^1 and b^{37} has a faint "companion" or component just outside the limits adopted, and therefore not shown. Wave-lengths can be read directly from the chart, to the tenth part of a tenth-metre, by estimating to tenths upon the scale, and suffixing the three figures thus obtained to 51: — for instance, the wave-length of b^4 will be

5164.3 tenth metres.

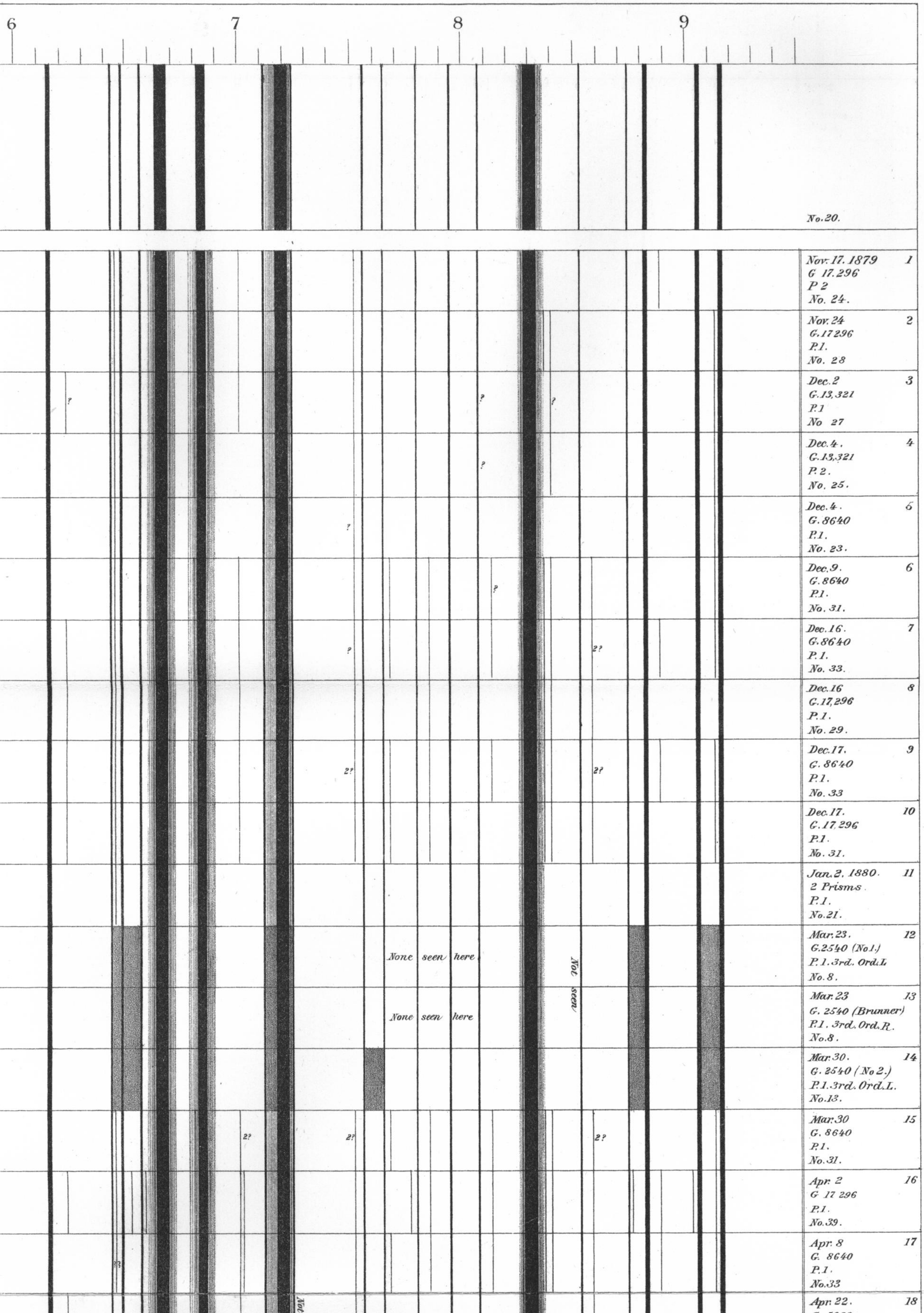
The relative intensity and character of the lines are represented as faithfully as possible; though it has been found exceedingly difficult to give any very good idea of the peculiar *blurred* or *burred* appearance so noticeable in the lines b_1, b_2, and b_4.

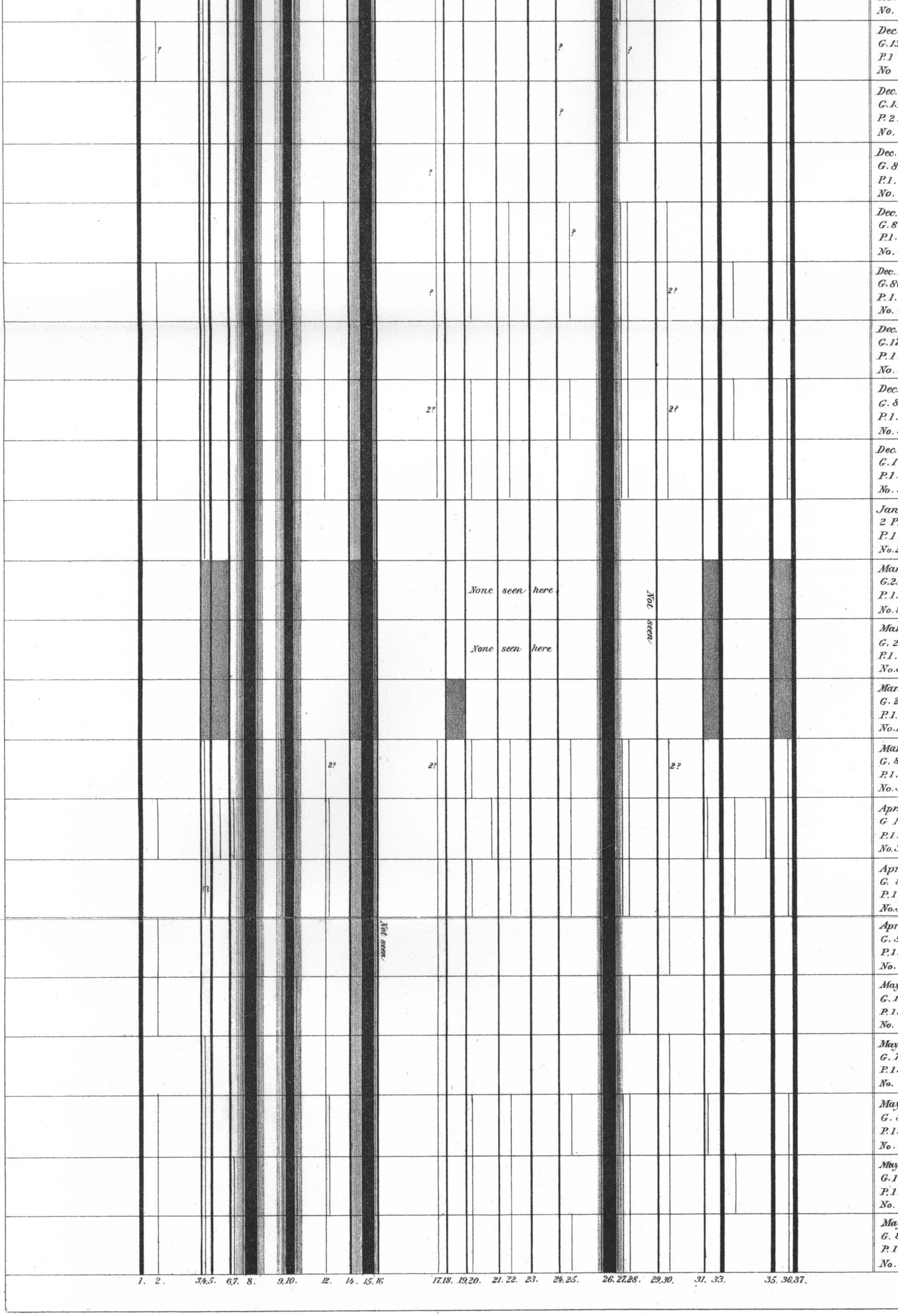
Comparisons.



Comparisons.

Plate I.




No.
Dec.
G.13
P.1
No
Dec.
G.13
P.2
No.
Dec.
G.8
P.1.
No.
Dec.
G.8
P.1.
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G.8
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Dec.
G.12
P.1
No.
Dec.
G.8
P.1.
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G.1
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Jan
2 P
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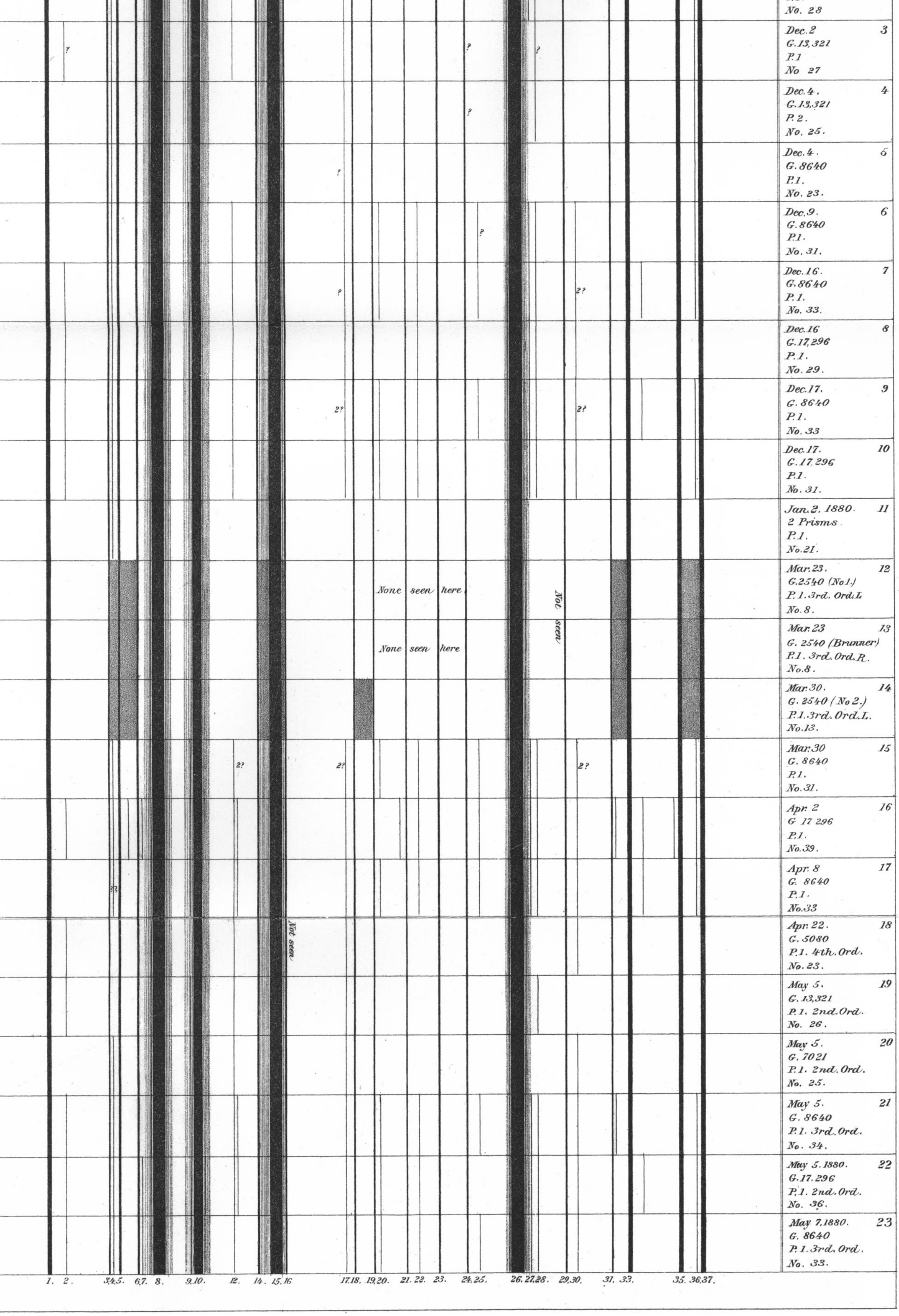
No. 28
Dec. 2 G. 13,321 P. 1 No 27 3
Dec. 4. G. 13,321 P. 2. No. 25. 4
Dec. 4. G. 8640 P. 1. No. 23. 5
Dec. 9. G. 8640 P. 1. No. 31. 6
Dec. 16. G. 8640 P. 1. No. 33. 7
Dec. 16 G. 17,296 P. 1. No. 29. 8
Dec. 17. G. 8640 P. 1. No. 33 9
Dec. 17. G. 17,296 P. 1. No. 31. 10
Jan. 2, 1880. 2 Prisms. P. 1. No. 21. 11
Mar. 23. G. 2540 (No 1.) P. 1. 3rd. Ord. L No. 8. 12
Mar. 23 G. 2540 (Brunner) P. 1. 3rd. Ord. R. No. 8. 13
Mar. 30. G. 2540 (No 2.) P. 1. 3rd. Ord. L. No. 13. 14
Mar. 30 G. 8640 P. 1. No. 31. 15
Apr. 2 G 17 296 P. 1. No. 39. 16
Apr. 8 G. 8640 P. 1. No. 33 17
Apr. 22. G. 5080 P. 1. 4th. Ord. No. 23. 18
May 5. G. 13,321 P. 1. 2nd. Ord. No. 26. 19
May 5. G. 7021 P. 1. 2nd. Ord. No. 25. 20
May 5. G. 8640 P. 1. 3rd. Ord. No. 34. 21
May 5. 1880. G. 17. 296 P. 1. 2nd. Ord. No. 36. 22
May 7, 1880. G. 8640 P. 1. 3rd. Ord. No. 33. 23
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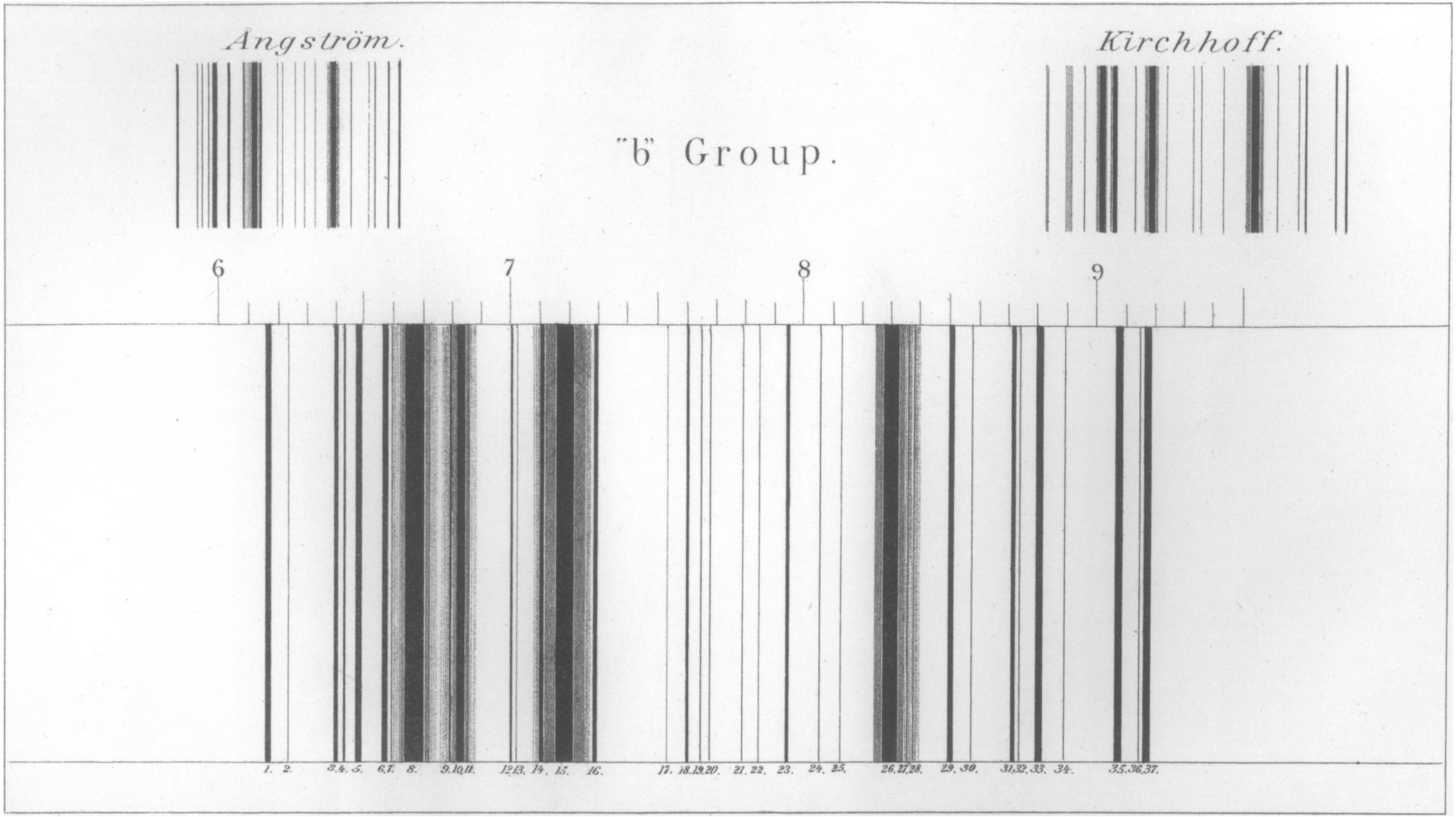
Plate II.


Angström.
"b" Group.
Kirchhoff.
6
7
8
9
1. 2. 3.4. 5. 6,7. 8. 9.10,11. 12,13. 14. 15. 16. 17. 18.19.20. 21. 22. 23. 24. 25. 26.27.28. 29. 30. 31.32. 33. 34. 35.36.37.